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AGN Variability Surveys: DASCH from BATSS to EXIST

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Abstract. Active galactic nuclei (AGN) are variable on a wide range of timescales, though relatively few systematic variability surveys have been conducted. Previous broad-band (both spectral and temporal) variability surveys of AGN are limited in their temporal and spectral bandwidth, despite their promise for probing the central engine and black hole mass. We outline optimal properties for variability studies and provide a brief summary of three new variability surveys, two (BATSS and DASCH) about to begin and the third (EXIST) possible within the next decade, which will open new windows on the physics and fundamental properties of AGN.

1. Introduction

A number of AGN studies have been undertaken for the variability of both optical (e.g. Peterson, these proceedings) and X-ray fluxes (e.g. Uttley, these proceedings) to enable constraints on the mass of the central supermassive black hole (SMBH) and to constrain emission models for the central engine, accretion disk and jet(s). Most of these have been with targeted narrow-field telescopes with observational cadence and total duration necessarily limited. The ideal AGN variability survey (AVS) would have the following properties, Pn:

1. *AVS-P1: broad sky coverage*, Ω, to maximize the number of AGN observed and to enable rare classes of variable objects, and low duty cycle events, to be found;

2. *AVS-P2: long total survey duration*, D, of survey observations which each detect minimum source flux S_{min} on timescale τ_o and with fractional uncertainty in flux δS_{τ_o} and enable variations on timescales from a maximum $\tau_{max} \sim D/2$ down to a minimum (median) $\tau_{min} \sim 0.7D/N$ to be measured from N randomly sampled observations; and

3. *AVS-P3: large total number of measurements*, N, to enable measures of source variability on timescales $\tau_n \sim (n-1)\tau_{min}/2$, where n = 2 ...N, and fractional variability sensitivity improves as $\delta S_{\tau_n} \sim \delta S_{\tau_o}/n^{0.5}$

Previous AGN variability studies have typically met only AVS-P3, and then usually with relatively short duration D. Broad-field (AVS-P1) AGN variability surveys are almost unknown, though the Swift/BAT survey (Markwardt et al 2005) with ~70% sky coverage per day has begun to open up this domain. Here we outline three new surveys that will each extend one or more of these AVS properties.

2. New AGN variability surveys

Time domain studies (e.g. PanStarrs and LSST) will unleash new constraints on AGN parameters and models by having one or more of the broad properties listed above. Already, optical and hard X-ray timing studies for full-sky AGN samples are beginning, and a far-reaching X-ray/γ-ray temporal-spectral survey could *EXIST* as an Einstein Probe in NASA's Beyond Einstein Program.

2.1. DASCH: Optical variability on scales $\Delta\tau \sim$ 10d –(50-100y)

Over the past 3y, we have developed an astronomical plate digitizer (Simcoe et al 2006) that is some 100X faster than any previously built in order to make available the Digital Access to a Sky Century from Harvard (*DASCH*). This will make possible (grant funding or a donor permitting...) the digitization and on-line access to the full images and derived photometry of Harvard's unique collection of some 600,000 astronomical images (all at least 5° x 7°) of the full northern and southern sky from c. 1880 - 1985. Astrometry to $\lesssim 1''$ is derived from WCS solutions for each scan and photometry from SExtractor isophotal analysis fits calibrated locally from the $\gtrsim$3000 GSC2.2 stars (B ∼8-15) typically on each plate (Laycock et al 2007). An example light curve (Fig. 1) for a random star in the open cluster M44, used for development of photometric analysis software, shows the $\lesssim$0.1mag (rms) photometry possible which for this dataset from 5 different plate series over 88y. Analysis of an initial sample of 15 bright (B

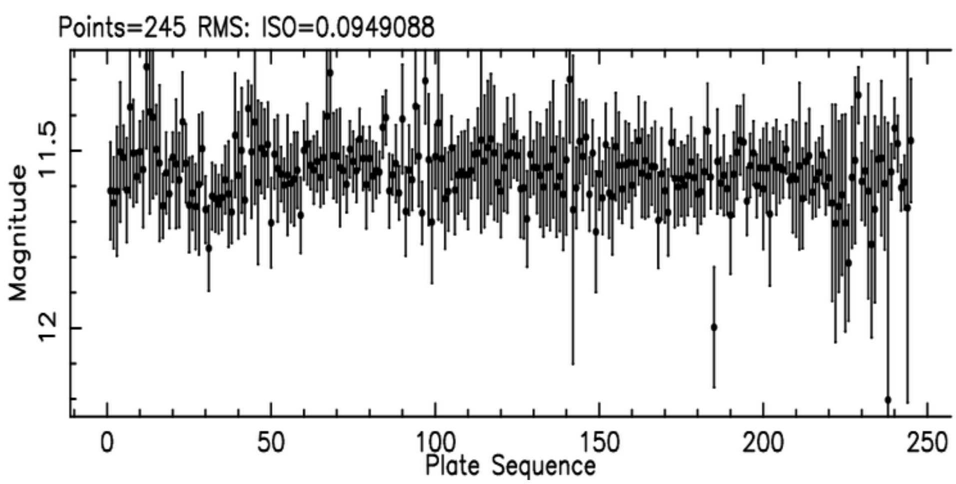

Figure 1. Partial lighturve (B mag vs. plate no.) for star (#399=GSC1395-2447) in the Open Cluster M44 measured on 245 plates (1890 - 1978). Even smaller rms errors are likely when annular calibration (on GSC2.2) is used vs. the full plate average done here since psf variations are then included.

$\lesssim$15) PG QSOs, starting with 3C273, is planned for a pilot study of variability power density spectra (PDS) to explore PDS break timescales τ_{bk} as a measure of SMBH mass. With ∼1000 plates for any given object randomly observed over ∼100y, the median sampling time is ∼25d and so the possible variability timescale range is $\tau_{max}/\tau_{min} \sim 50y/25d \sim 730$. Allowing for $\gtrsim$3 timescale

measures above a PDS break to determine τ_{bk}, the corresponding SMBH mass range could be constrained over dynamic range of ∼240.

2.2. BATSS: Hard X-ray variability on scales $\tau \lesssim$ 100s–1d

We have also initiated a "BAT Slew Survey", BATSS (Copete et al 2007) using the BAT hard X-ray imager (Barthelmy et al 2005) on Swift to analyze "event-mode" data from the ∼60 slews (∼1-2min each) that Swift performs each day to slew on/off pointed targets. Whereas BAT pointings cover some ∼70% of the sky each day, adding in the slews increases sky coverage to nearly 100% as well as provides the only high time resolution data (apart from GRBs) since BAT pointing data is binned on 5-7min timescales. BATSS will thus provide AVS-P1,P3 and be particularly well suited to detect rare, bright AGN flares such as the extreme Blazar events from PKS2155-304 for which Swift/XRT/BAT coverage did not quite overlap with the 8 and 17Crab(!) TeV flares reported by HESS (Foschini et al 2007). Although the XRT spectra indicate that the synchrotron spectral break for this Blazar is below the BAT band, the BAT Transient Monitor (Krimm 2007) clearly does see flare variability from others – e.g. Blazar Mrk 421 (Fig. 2) for which extreme flares could be seen by BATSS.

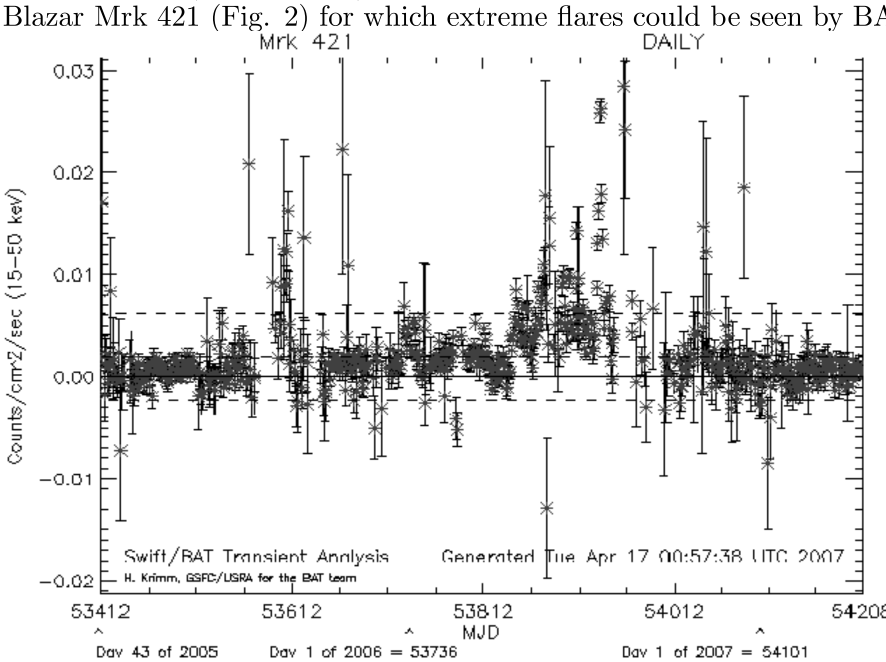

Figure 2. Swift/BAT 2y lightcurve for Blazar Mrk421 showing ∼100mCrab flares that might be resolvable (and still brighter) by BATSS.

2.3. EXIST: Ultimate hard X-ray variability on scales $\tau \lesssim$ 10s–5y

The best prospects to optimize properties AVS-P1-P3 are with the *EXIST* mission (http://exist.gsfc.nasa.gov/), proposed as the Black Hole Finder Probe in NASA's Beyond Einstein Program. *EXIST* images the full sky 3-600 keV each 95min orbit with two large area and field of view (FoV) coded aperture telescopes (Grindlay 2005 and Grindlay et al 2007). With daily full-sky flux sensitivity S_{min} ∼1mCrab (comparable to Swift/BAT in 1y) due to nearly 20%

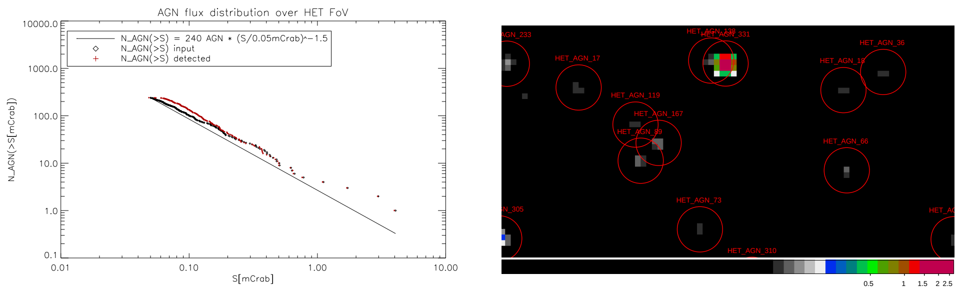

Figure 3. Simulated 1y *EXIST* logN-logS for 21° x 21° field of view of one sub-telescope containing 331 AGN and 4° x 2° zoom image including brightest (4mCrab) source and 12 other AGN with fluxes from ∼0.05 – 0.28mCrab.

continuous coverage on every source enabled by continuous scanning with its large FoV and total area, *EXIST* would detect and study $\gtrsim$3 x 10^4 AGN full sky. Each is located to $\lesssim 11''$ (90% confidence radius) which allows unambiguous host galaxy identification for its 0.05mCrab (=5 x 10^{-13} cgs, 40-80 keV) 5σ survey threshold sources. A simulated 1y survey image and logN-logS is shown in Fig. 3 with normalization from Treister and Urry (2005) including obscured AGN. Thus, ∼300 AGN (full sky) can be measured on timescales τ_{min} = 1d or ∼1000 AGN with τ_{min} = 6d. For a 5y mission, AVS-P3 gives N = 1800 and 300 timescales, respectively, to constrain the PDS and τ_{bk} and thus SMBH mass.

3. Prospects for SMBH mass, demographics and evolution

Given the τ_{bk} vs. mass scaling found by Uttley et al (2002) from RXTE data on several AGN, *EXIST* and possibly DASCH can constrain SMBH masses in AGN over a range $\sim 10^{7-9.5}$ $M_\odot$, with $\gtrsim 10^9 M_\odot$traced out to z $\lesssim$3. Non-AGN SMBHs (e.g. SgrA*) can be identified by their tidal disruption of main sequence stars and accompanying hard X-ray flares detected by *EXIST* and optical flares detected by DASCH for non-obscured systems. Together with extreme Blazar events from BATSS, the prospects for new AGN variability surveys are timely.

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